DESIGN , FABRICATION AND ANALYSIS OF A HEXAPOD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology(Dual Degree)

In

MECHATRONICS AND AUTOMATION

By

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National Institute Of Technology

Rourkela

C E R T I F I C A T E

This is to certify that the thesis entitled**, "DESIGN , FABRICATION AND ANALYSIS OF A HEXAPOD"** submitted by **Mr. SHEAK AFTAB ALLI** in partial fulfillment of the requirements for the award of Master of Technology Degree in **MECHANICAL ENGINEERING** with specialization in **"MECHATRONICS AND AUTOMATION"** at National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Department of Mechanical Engineering

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ABSTRACT

The principle motivation behind the work is to present a fully fabricated Hexapod. Hexapod is a robot that has six legs for movement and thus quite a number of degree of freedom. . Numerous studies have been completed in examination focuses. Moving robots have pulled in significant consideration for a very long while now, on the other hand, just as early as this past year scientists have produced navigator robots, planned and assembled to fulfill the imagination, with exhibitions that can be suitable for handy applications. This paper gives an outline of the best in class on hexapods by alluding both to the early plan arrangements. Cautious consideration is given to the fundamental design issues and requirements that impact the specialized possibility and operation execution. A design flowchart was plotted with a specific end goal to efficiently plan a hexapod. Since the robot has numerous legs, the robot is effortlessly customized to move around in light of the fact that it can be designed to numerous sorts of gaits, for example, tripod, and wave, ripple and quadruped gaits etc. House of quality was used to compare and finalize among the probable design. A novel design has been created with CATIA. Mainly, the undertaken design outline takes into account the fundamental features, such as basic structure and mechanical configuration, electronics schematics, motion planning, payload, and walking gait. Kinematic as well as Dynamic Analysis had to be done using DH forward and Inverse matrix method. Simulation has been done in V-rep and excel simulator. Stress and displacement analysis was done for the feasibility of the model to sustain the weight of the body. Estimated physical parameters have been calculated. Control system design, gait implementation body manufacturing has been discussed. Bill of materials was generated and fabrication of Hexapod was completed. Future possibilities have been discussed.

Contents

LIST OF FIGURES:

LIST OF TABLES

Table no. Page No.

CHAPTER 1

INTRODUCTION
&
REVIEW OF LITERATURE

1.1. Introduction:

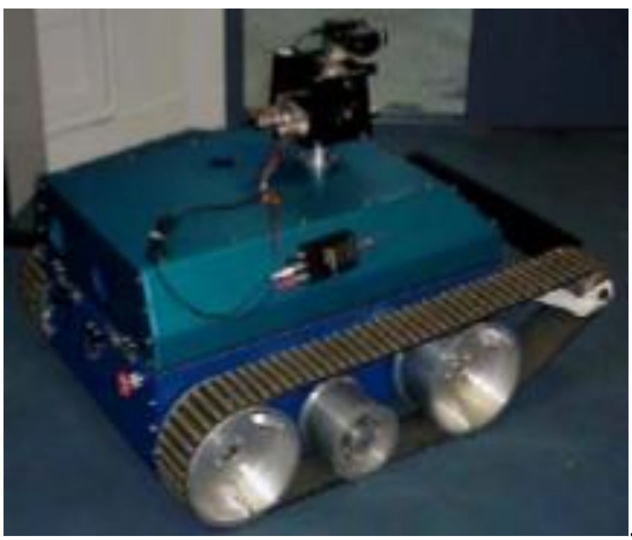
Dominance of six legged species in insect world is quite clear and obvious. They use the six legs for bigger stability base and also the higher number of degree of freedoms being available helps in moving in uneven terrain faster and smoother. Hence the concept of Biomimetic hexapod to dominate the robot world in context of stability. With the vast use of hexapods in future we can excavate mines, explore extra-terrestrial bodies, simplify search and rescue mission and thus overall making human life hazard free and safe. Use of Hexapod by ESA in Rosetta mission showed the world an idea for movement of robots on the surfaces of extra-terrestrial bodies. Current advancement of Mangalyaan mission using serial Hexapod is worth mentioning. With India’s ambitious Mar’s mission II coming up real soon, the extensive research in the field of hexapod is speeding up. This gives me the motivation to undertake this project.

1.2. Literature Survey:

1.2.1. Classification of Mobile Robot:

Basically, mobile robots are classified according to their characteristics, as in: movement, control, Uses, and body structure. From body structure, robots can be classified again as aquatic, aerial or terrestrial. The last one is the most known one and it again diversifies into three parts; having wheels (Fig. 1), tracks (Fig. 2) or legs (Fig. 3). As per control type, remote controlled; movements being defined by operator, semi-autonomous, where an operator gives all the commands that will be executed by the bot, and lastly, autonomous; robot is intelligent enough to make own decision, making their own shortest path. Considering the uses, we have: service robots for household tasks, industrial for production line, field robots for rough and un navigable environment. There are also personal robots that are being sold in packs. Interaction with humans are their primary task. Holonomic and Non-holonomic is how we can divide the robots as per the comparison between number of total degree of freedom and number of controllable degree of freedom.

Figure 1.1: Wheels for movement.



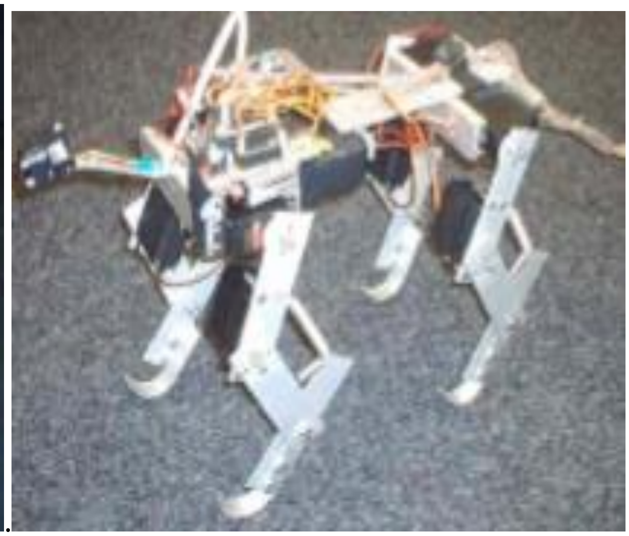


Figure 1.2: Tracks for movement.

Figure 1.3: Legs for movement.

Above classification helps in defining robot for its work. Figure 4. Shows robots for internal use, as in, industry, project work, film industry, cleanliness. Figure 5. Shows us the external use robots for use of agriculture, for forest, mines etc. and even on extra-terrestrial bodies.

The work we focus here is on Hexapod. The motivation for this work has been drawn from the use of Hexapod in recent advancements in space research and India's ambitious Mar's mission.

Figure 1.4: NEDO robots.

Figure 1.5: Forest Robot, by SRI..

Figure 1.6: Sojourner; first robot in Mars.

1.2.2. Literature Review of Hexapod Structure:

The mechanical and operational mechanism of a hexapod robot is in view of creatures (basically insects), from the biomimetic standards [4], science in light of the impersonation of existent components in nature, attempting to take in its working sand applying such information in the undertaking of simulated instruments like the natural ones. "Bio mimetic" is the merging of the Greek expressions "bios", which implies life, and "mimesis", that implies impersonation. Accordingly, it might be said that the biomimetic is the impersonation of living things. These days, the biomimetic speaks to an examination zone that is in awesome advancement in the field of the science and innovation.

Innovation rises speedier by adjusting another’s thought to add to one’s design, model and new framework control. LAURON is a standard sample; a six-legged robot which has been created at the Forschungszentrum Informatik Karlsruhe (FZI) in Germany. The primary LAURON project was constantly enhanced until the most recent task called as LAURON IV [1]. The hexapod robots have different sorts and capacities. Mnay are truly straightforward in the outline and control structure, where as some are of complex structure and control. Case in point, in the operation framework, the robot [2] is fit to perform different tasks utilizing a remote control at unsafe range which is can't be secured in person. Viz. observing radiation risk.

Figure 1.7: LAURON hexapod created by FZI.

1.2.3. Literature Review of Control System:

The designs of hexapods from every papers have ample amounts of particular contrasts. RHex grew by [3] utilized Maxon sort motor with a 33:1 gear reduction fueled by a 22V cell. The robot leg has 2 DOF. As indicated by the author, the strategy is anything but difficult to construct and keep up the robot and no friction amid springy movement. This is most appropriate for stair climbing. Another, Bill-Ant-P robot done by [4] was fabricated with carbon fibers and 6061 aluminum. It utilizes MPI MX-455HP hobby motors for its maneuverability, more torque value, and more DOF movement. They have 8.35kg-cm of torque, can turn around a 60 degree in 0.18sec, and has a smaller dc motors that devours 1155mW of torque at standing torque.

The paper presented by E. Burkus et.al. [5] discusses about ‘Gregor’. This robot improvement model had Autodesk Inverter 9.0 to characterize attributes of the components, for example, weight. To arrange of the limitations that can be effortlessly traded into the dynamic simulation process, Rhinocerus 2.0 software was used. MSR-H01 hexapod grew by Micromagic System was designed and assembled from 26 accuracy laser-cut 5053 aluminum components [6]. Hexapod designed by D. Belter et.al.[7 controlled 18 servos by interfacing it with the Arduino Decimilla board ,which was favored above other micro controllers. Theye did this by using Devantech SD-21 board. The product utilize Matlab to control the servo controller.

To control the robot leg, Jacobean Inverse matrix method was utilized to characterize the position of joint, angle and legs. The notes by Polulu Co-operation showed that hexapod can use Dynamixel RX-28 by ROBOTIS [8] as joint servos, which is a complex actuator module. The control board taking into account the 16-bit AVR ATmega256 and cable communicates with external personal computers. The controller to robot communication was done by sending data parcels to joint servos and various sensors and vice-versa. The main controller communicated with the robot by sending and accepting data parcels to the servos and sensors. Ragno [9] was built of the dimension, 33 cm long and 30 cm wide. It weighted 2.15 kgs. Wireless communication as in Bluetooth was used for serial communication between the on-board and off-board parts.

1.2.4. Literature Review of Robot Movement:

The robot's forward movement using hexapod legs is called gait [7]. There are mixtures of walking pattern available and the well-known gait utilized by hexapod is called

Tripod stride. In this tripod walk, three feet of hexapod is dependably in contact with the ground for the entire time [10]. The journal by [2] shows how the author utilized tripod stride in light of the fact that it is stable. The initial phase in walk, angles the beginning stance of all legs is chosen, and end point position is characterized as the "reference position". In the work published by [8], the hexapod robot likewise utilize tripod walks, the body component and bolstered by three legs. The work is centered on the energy development of bot, Kinetic mechanism and the path taken [12]. It is about the practicality on how the robot navigates. The imperative viewpoints thought seriously about are the inertial edge, train referenced direction arrangement of suspension.

In catastrophe recovery [11], mentioned bot utilized a couple of variety of gait ment to move it in at all sort of landscape. On even landscape, the gait utilized is alternating while on uneven territory, Wave gait is preferred. The most back leg is begin made headway while we compare it to all the other legs. The stride is exceedingly steady since one leg is lifted above the ground at once. Main purpose behind picking this gait is the best strength edge for uneven territory route. Wave walk motion embracing the control calculation with an angular position data and torque command yield [9].

CHAPTER 2

OBJECTIVES
&
FLOW CHART OF PROCESSES

2.1. Objectives of the project:

Primary objective of the project is to materialize the design and fabrication of Hexapod in the given time frame. In which the sub-divisions are,

1. Research on Biomimetic Hexapod
2. Identification of key features and main design characteristics of Hexapod.
3. Building a solid 3D model of the robot using CAD software.
4. Validation of the CAD model by Kinematic and Dynamic simulation.
5. Use of V-rep, Excel sheet for simulation.
6. Material procurement for the simulated model.
7. Writing algorithms for control of hexapod using adequate Gaits.
8. Write the PIC program for this robot.
9. Optimization of the control system.
10. Assembling the Hexapod in line with the 3D model.
11. Demonstration of final Hexapod.
12. Realization of further improvements.

2.2. Flow chart of processes:

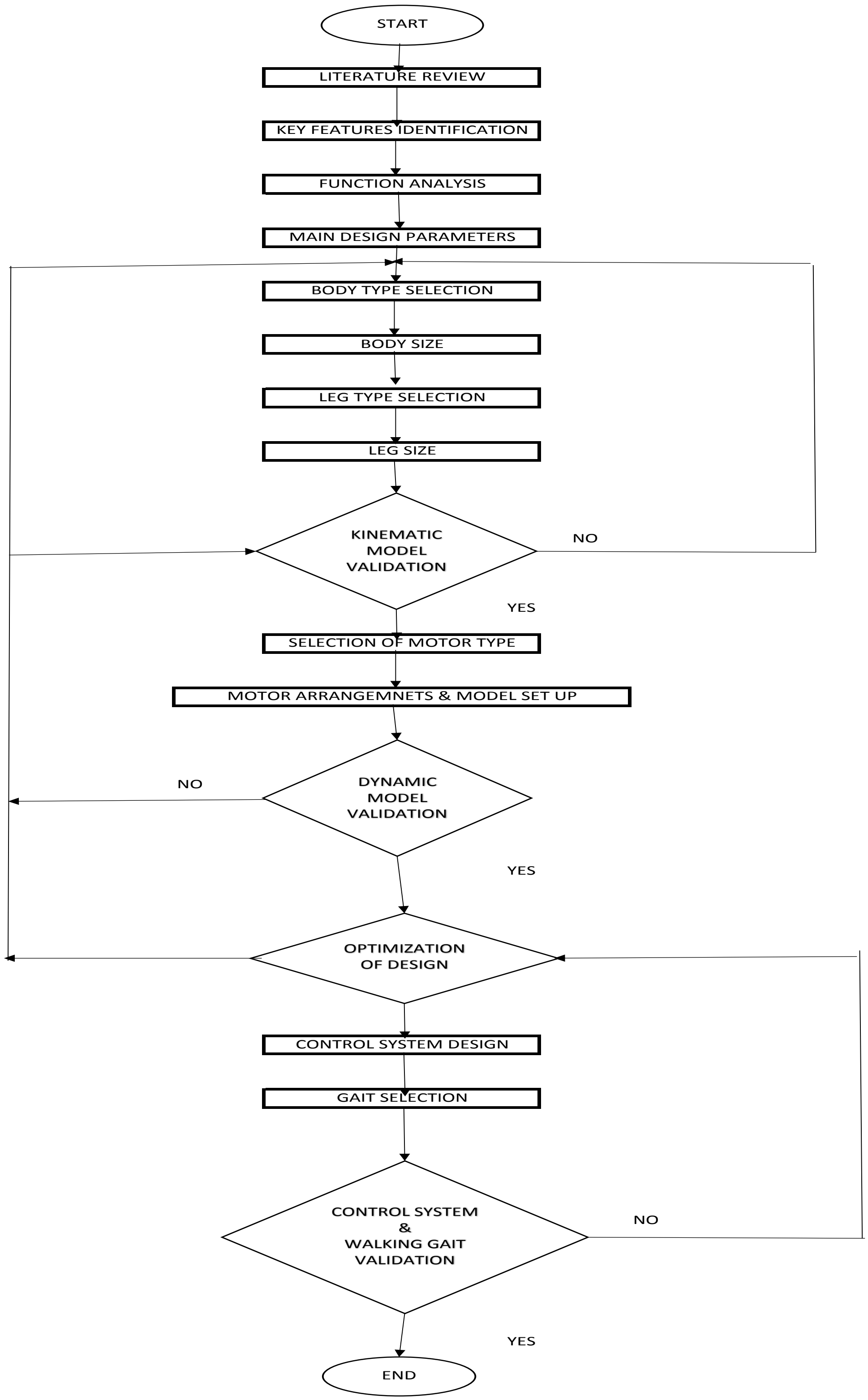


Figure 2.1: Flow chart of process

CHAPTER 3

DESIGN DRAFT OF HEXAPOD

3.1. Classification of Hexapod:

Hexapods are broadly classified into two different category.

1. Circular (Radially symmetric)
2. Rectangular (axis symmetric)

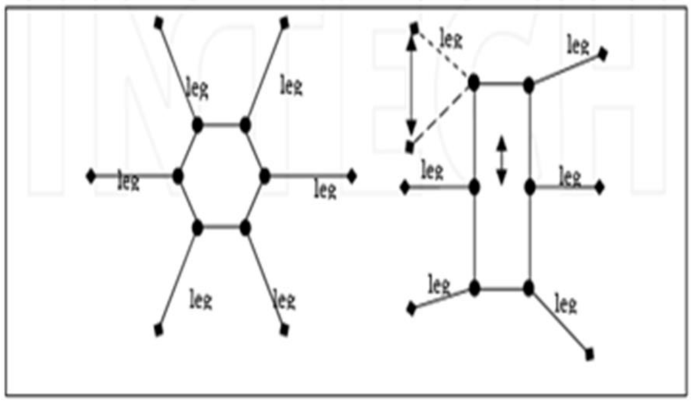


Figure 3.1: Circular and Rectangular hexapod

3.2. Modelling of Bio-mimetic leg:

The nature inspired leg of a hexapod is basically consists of four major parts.

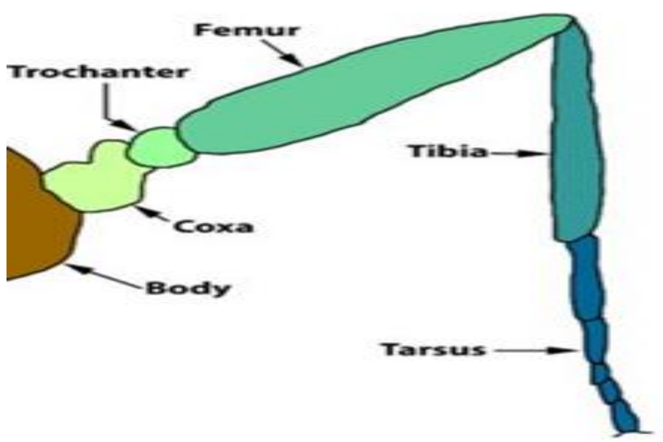


Figure 3.2: Biomimetic leg

These parts more or less remain same across the insects' family. Tarsus is neglected for design.

3.3. Degree of Freedom Calculation:

Each leg has three degree of freedom neglecting Tarsus. This can be shown as a RRR manipulator. The body of the hexapod can also move in six different directions in the three axis providing it a total of six degree of freedom. Hence total number of unrestricted degree of freedom enjoyed by a hexapod is 6*3+6= 24 DOF.

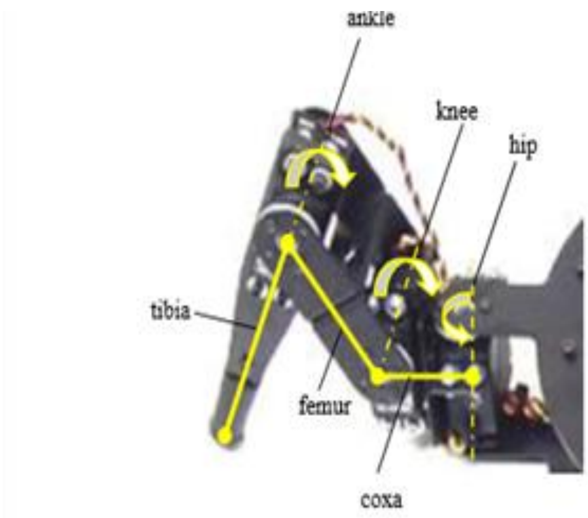


Figure 3.3: Revolute joints in Hexapod leg

3.4. Structural Model of Hexapod :

This segment of the work talks the subtle elements on how the physical model is being created. The improvement begins by outline and portrayal a few design of hexapod robot with distinctive angle and criteria until to the basic schematic design before the hexapod robot stands on its feet for being tested. The plans of hexapod had been designed in eight distinct outlines and with each having their diverse shapes, criteria, details, preferences and weaknesses. The eight plans of the hexapod robots are indicated in Table 2. From the outlines specified in Table 2.a, the main specification of every robot are portrayed in the Table 3. The detail of the robots covers a couple of fundamental angles.

Our leg design should be based on three major factors.

1. As light weight as possible
2. Minimum Bending in all direction
3. Can support the weight of the robot.

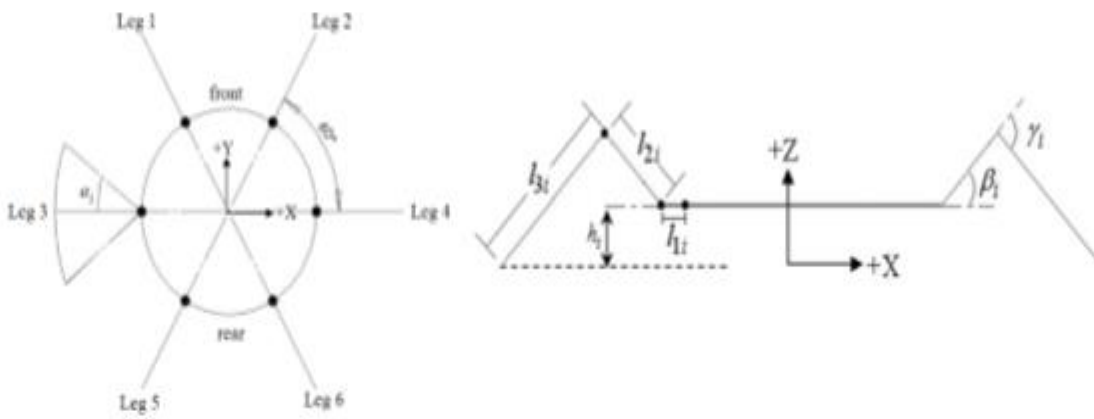


Figure 3.4: Design parameters of Hexapod

Segment No.	1	2	3
Segment Name	Coxa	Femur	Tibia
Segment Length	$l_{1i} = 40\,mm$	$l_{2i} = 80mm$	$l_{3i} = 90\,mm$
Joint Name	Hip	Knee	Ankle
Joint Angle	$-\frac{\pi}{2} \leqslant \alpha_i \leqslant \frac{\pi}{2}$	$-\frac{\pi}{6} \leqslant \beta_i \leqslant \frac{\pi}{2}$	$0 \leqslant \gamma_i \leqslant \frac{2\pi}{3}$

Table 1: List of design dimensions for hexapod

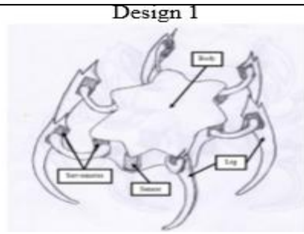
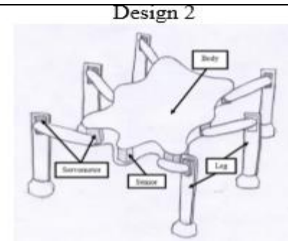
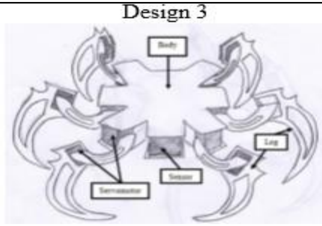
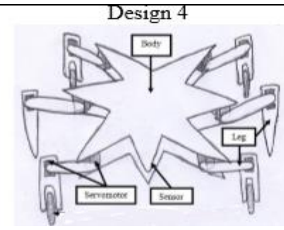
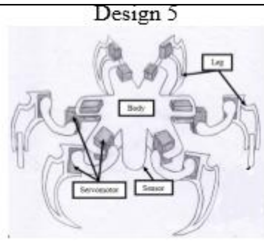
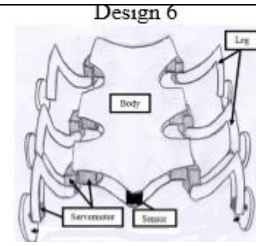
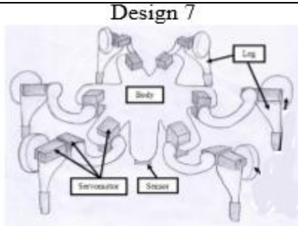
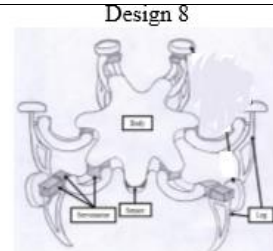
Design 1 	Design 2 
Design 3 	Design 4 
Design 5 	Design 6 
Design 7 	Design 8 

Table 2.a: Probable designs of Hexapod

DESIGN	SPECIFICATION
1	12 servomotors
2	16 servomotors
3	12 servomotors
4	12 servomotors
5	14 servomotors
6	12 servomotors
7	18 servomotors
8	18 servomotors

Table 2.b: Design specifications of Hexapod

3.5. Design Selection by House of Quality:

House of Quality is one of the co relation matrix used to choose the design keeping in mind the diverse aspects of the project. The house of quality is a matrix in shape of a house, structured in such a way that it is being utilized to characterize the relationship between the client needs and the out coming product’s necessities. Taking into account the House of Quality, there can be two diverse need which are configuration prerequisite and client prerequisite. The ratings given are from positive solid positive, positive, negative, and solid negative. One side shows who’s who and the other side represents who vs how. The device sequences the outcome of the relation matrix from the most vital viewpoint to the less imperative.

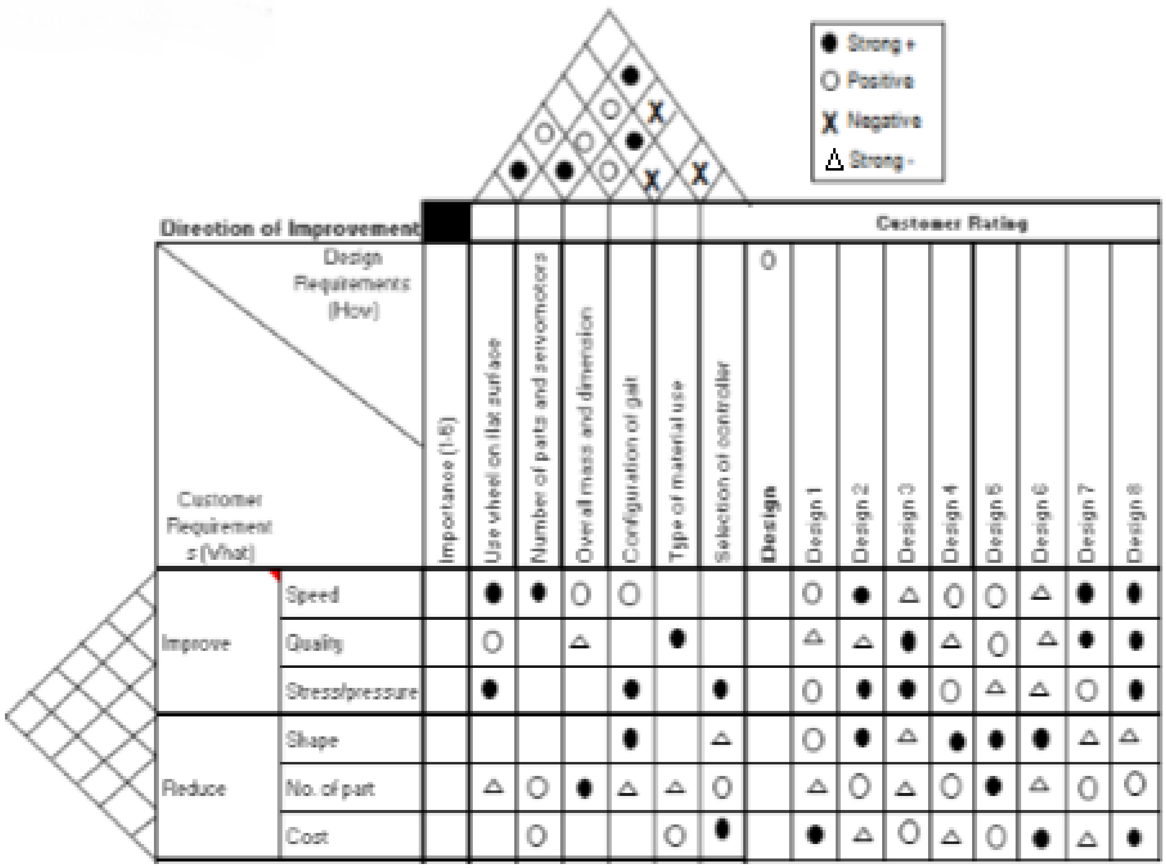


Table 3: The correlation matrix in line with Table 2.

Major design issues that are vital for the design consideration are listed below:

- The anatomy
- Maximum permissible size
- Actuation
- Control system
- Electronic Schematics
- Power consumption
- Gaits type
- Allowable speed
- Payload
- Autonomy
- Total manufacturing cost.

3.6. Drafting using CATIA :

After deciding the best case design we moved to the software drawing of hexapod. We had to know the dimension of each part of robot for that. CATIA software by Dassault systems was used for the design. CATIA stands for “Computer Aided Three Dimensional Interactive Application”. CATIA is user friendly. It gives real images, detail portraits, and steps for demonstrating design. It also supports surface modelling. It provides with unique drafting operation which can be handy with details while true prototyping. It also provides simulation, animation, weight estimation by applying materials to robot body; which includes both metal and non-metal. Using this material selection acrylic sheet and aluminium was chosen to build the robot boy for their light weight. Using CATIA one can also export or import part files, drawings to or from other software.

Steps followed in CATIA design are:

- Part modelling of the different parts of the robot in CATIA V5 starting with leg. (using the element of symmetry helps in design)
- Assembling of the parts in CATIA V5.
- Defining of joints and contacts for the robot in CATIA SimDesigner.
- Drafting of the novel design.
- Exporting of the design for further simulation using V-rep and ADAMS.

For CATIA design the aforementioned dimensions in table were used. The platform diameter is taken as 110 mm. Although there is still scope for future improvements and corresponding changes in the design of Hexapod.

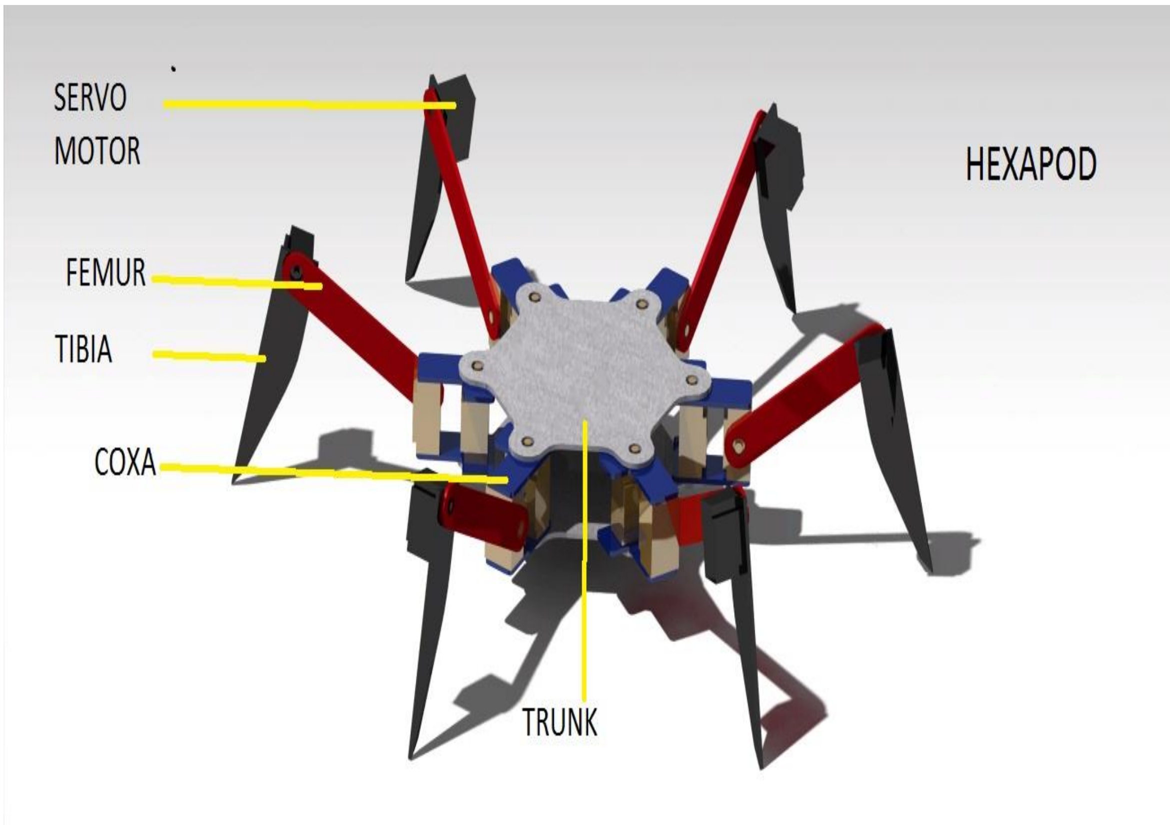


Figure 3.5.a: 3D model designed in CATIA.

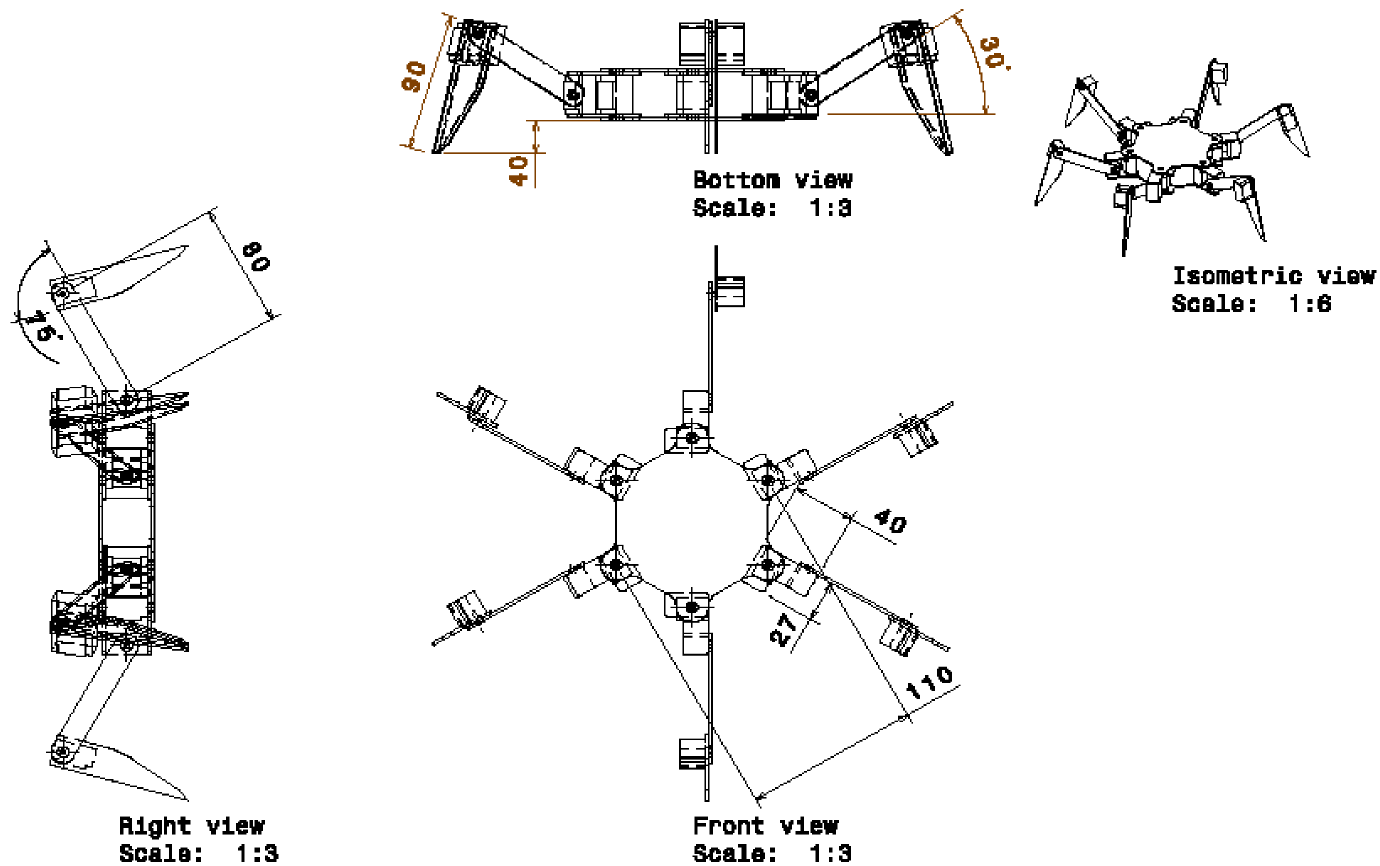


Figure 3.5.b: Drafted 3D model with dimensions.

CHAPTER 4

DESIGN ANALYSIS

4.1. Kinematic Analysis:

For a stable and balanced structure, the COM (center of mass) of the robot must lie inside the circumference made by the pivot points. Best case scenario is the COM should lie below the circle made by the point of pivots of tibia for stable equilibrium, but not necessarily. If the COM is outside the circle, the robot will fall off.

Forward Kinematics is the part of kinematics where the end position is being calculated. In case of a serial link i.e. the leg of the robot, it is the position of end effector in frame of reference of the COM. If we know the servo position, link lengths, and angles, we can know the end points of the leg. Thus this kinematics is deterministic, as there can be only one solution to the equation. But it is hardly useful here. As giving a servo a motion leads us to only one point. But if end point changes, the entire leg have to change the orientation.

This leads us to Inverse Kinematics. Inverse Kinematics can be solved in two different ways.

Analytical-

Geometry is of course one way of solving the Inverse Kinematics. It helps when the number of links are less. You can simply draw the arms using the angles shown, and the equation can be solved. It is basically a hit and trial method.

A more efficient way is matrix multiplication. Rotation and translation matrix is being used for the reverse translation of the end point to the base point. In hexapod each leg can be a RRR manipulator hence rotation matrix is multiplied thrice for calculation.

Iterative-

For the realization and smooth transition of complex chain, Iterative is more efficient. We reach the end point by starting from any joint position and then using iterative methods. The iteration helps taking the end point towards the target. Dot product and sine inverse functions were being used for the final solution.

- Here we chose Analytical method for Kinematic analysis.

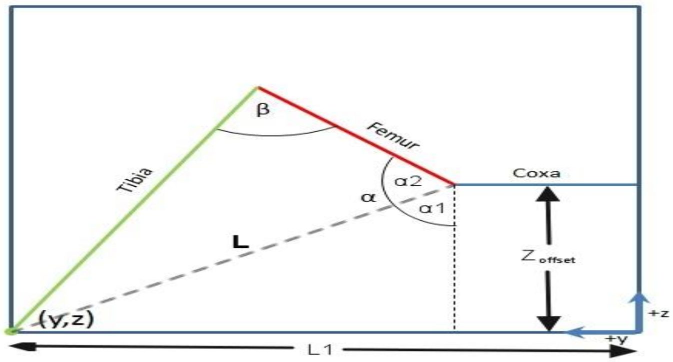


FIGURE 4.1.a: 2D representation of 3D leg

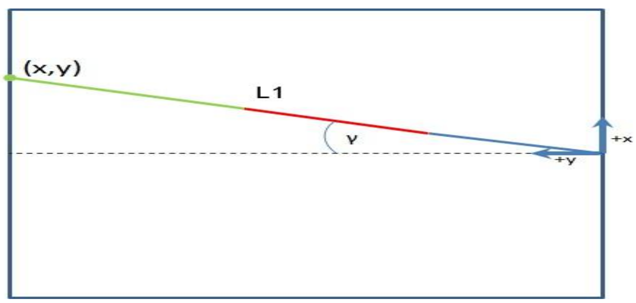


Fig.4.1.b: Leg in XY plane

Here,

$$\frac{x}{y} = \tan(\gamma)$$

$$=> \gamma = \tan^{-1}\left(\frac{x}{y}\right) \qquad \text{…Eq. (4)}$$

Now, splitting α in two halves for calculations:

$$L = \sqrt{(offset)^2 + (L1 - coxa)^2}$$

$$\propto_1 = \cos^{-1}\left(\frac{offset}{L}\right) \qquad \text{...Eq. (5)}$$

Now, using COSINE law,

$$T^2 = F^2 + L^2 - 2(F)(L)\cos(\propto_2)$$

$$=> \propto_2 = \cos^{-1}\left\{\frac{T^2 - F^2 - L^2}{-2(F)(L)}\right\} \qquad \text{...Eq. (6)}$$

$$\propto = \propto_1 + \propto_2$$

Hence,

$$=> \propto = \cos^{-1}\left(\frac{offset}{L}\right) + \cos^{-1}\left\{\frac{T^2 - F^2 - L^2}{-2(F)(L)}\right\} \qquad \text{...Eq. (7)}$$

And,

$$L^2 = T^2 + F^2 - 2(T)(F)\cos(\beta)$$

$$\beta = \cos^{-1}\left\{\frac{L^2 - T^2 - F^2}{-2(T)(F)}\right\} \qquad \text{...Eq. (8)}$$

Using this formula we can calculate the angle values for servos.

4.2. Excel sheet simulation:

Using the aforementioned formulas excel sheet simulation was carried out with taking the dimensions in calculation and the resulting points were used for the control of Hexapod.

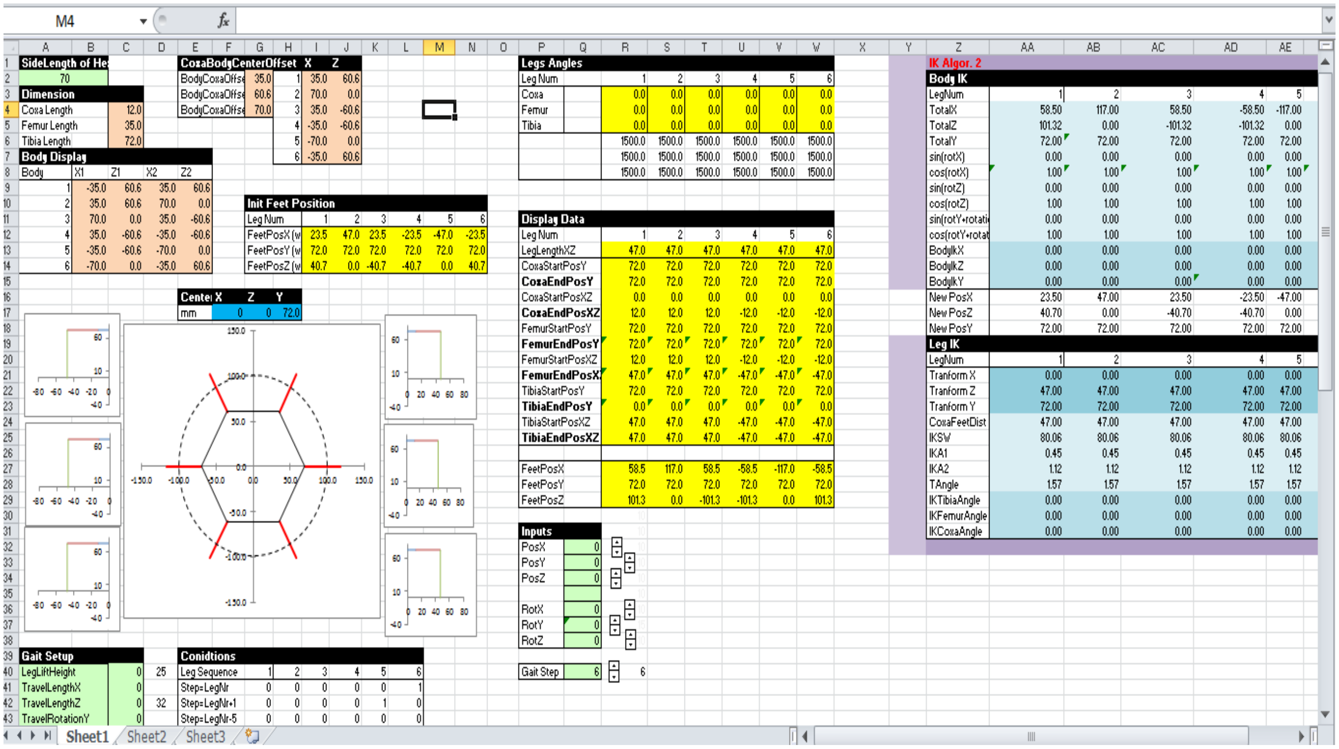


Figure 4.2: Excel sheet simulation of IK

4.3. V-Rep Analysis:

Analysis of the design and simulation are the ways to eradicate or short out manufacturing delays due to design imperfection, and hence the cost of prototyping. V rep analysis thus helps in the better understanding of simulation. It helped in creating embedded scenario and applications for robot. Basically 3D simulation helps in understanding and validating the design. V-rep is one of those robotic simulator. It is developed by 'Coppelia Robotics' and is written in the programming language 'LUA'.

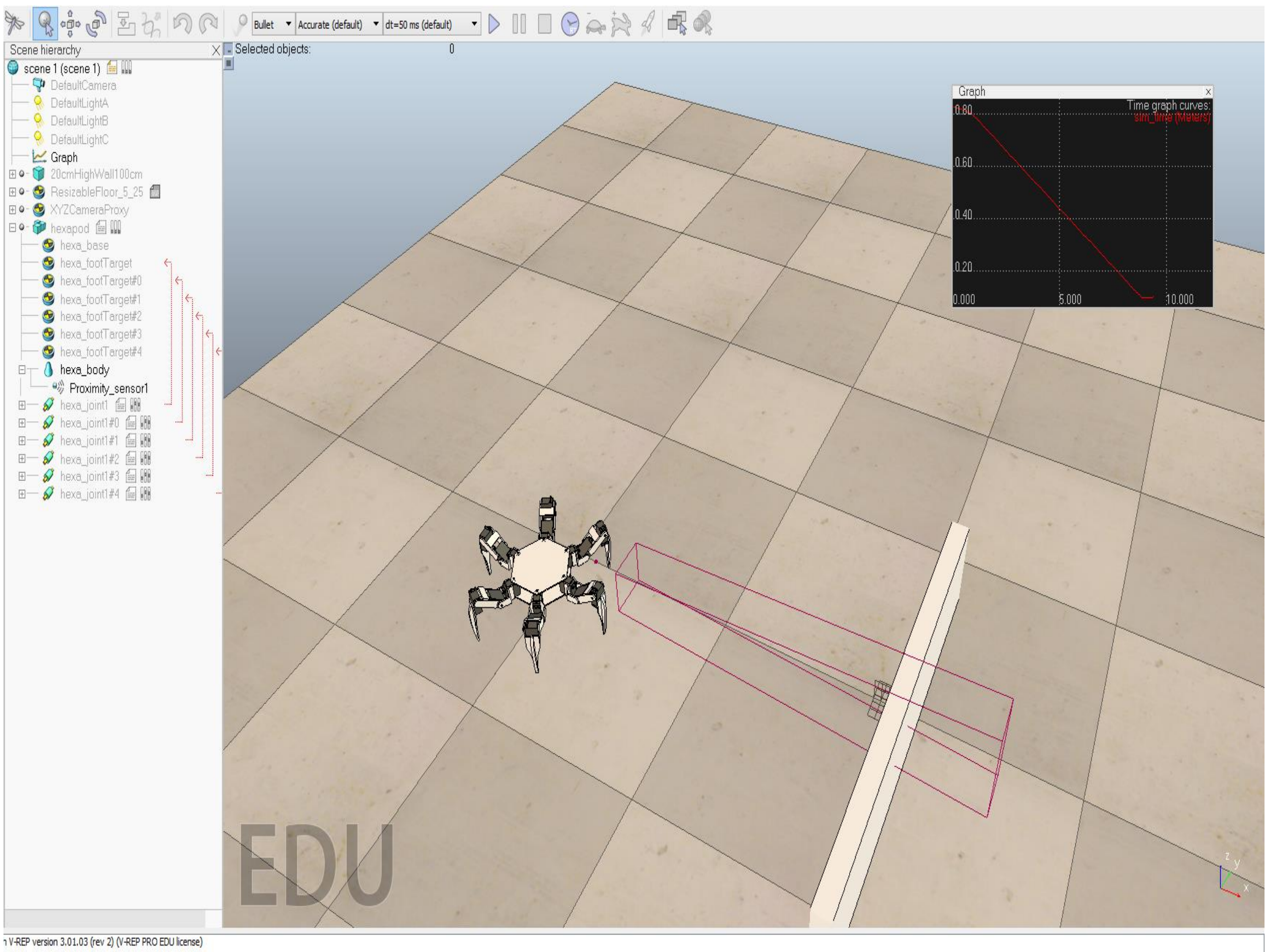


Figure 4.3: User interface of V-rep showing the Hexapod.

For better understanding of dynamics a simulation of Hexapod using V-rep was done and results were discussed.

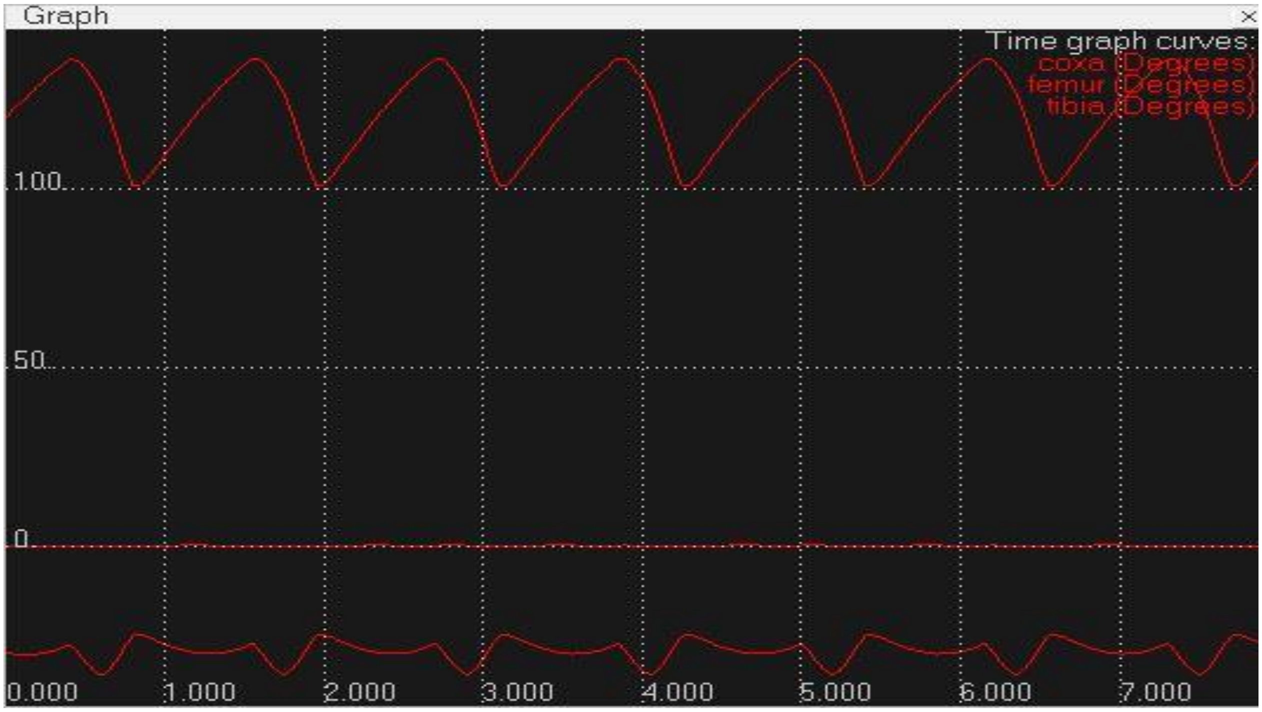


Figure 4.4.a: Joint Displacement

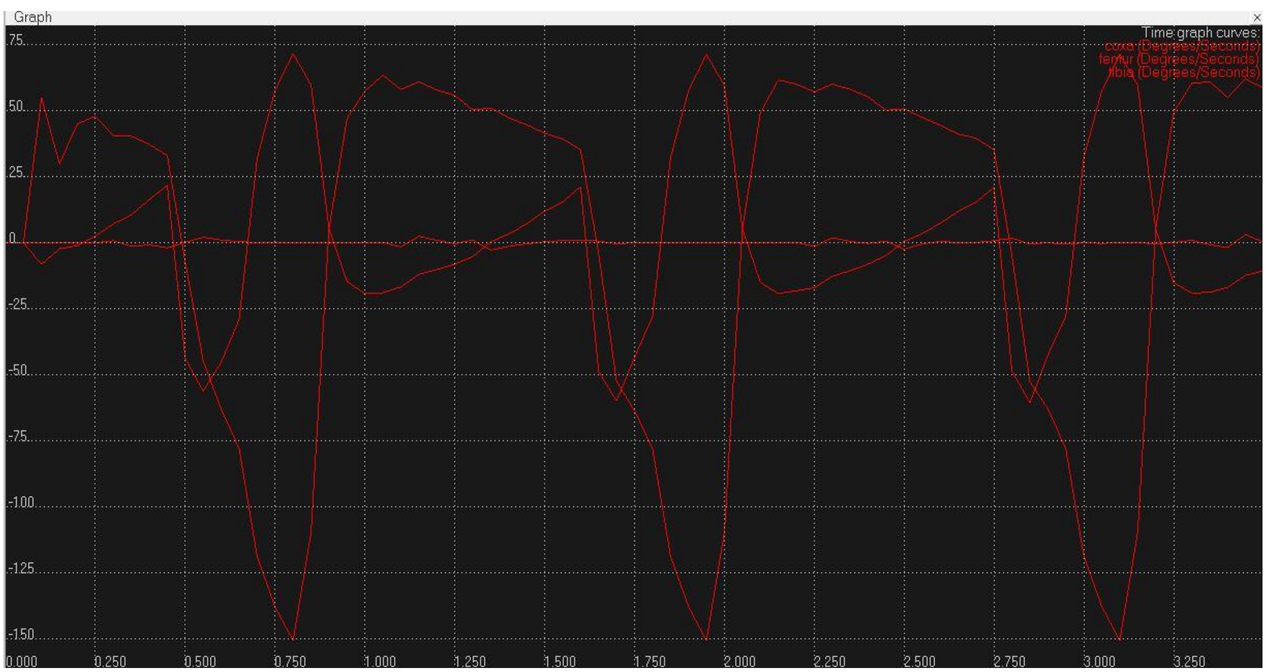


Figure 4.4.b: Joint Velocity

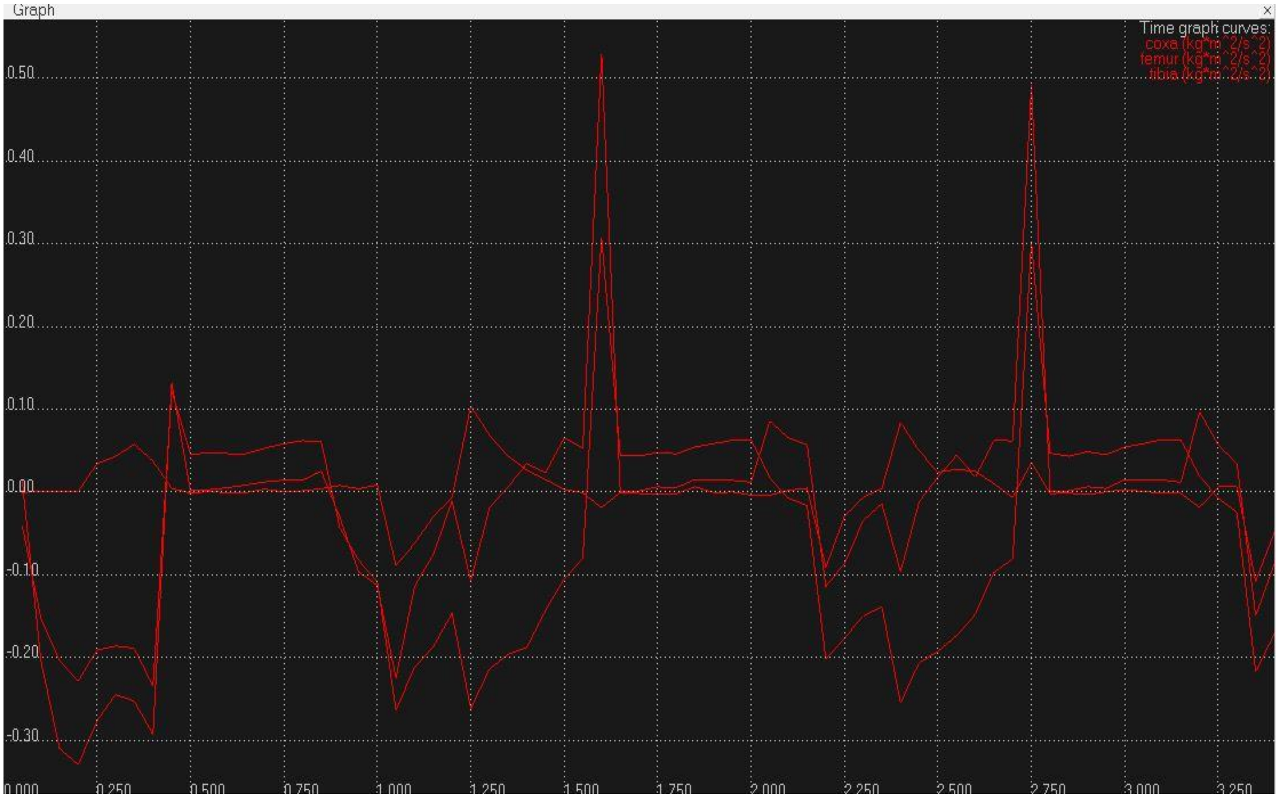


Figure 4.4.c: Joint Torque

CHAPTER 5

COMPONENT SPECIFICATION

5.1. Bill of Materials:

As this is my first time attempt to build a hexapod, my attempt was to build it first with small weightage servos staying in the budget constraints. Also I had keep in mind the dimensional restrictions the selection of servos brought with them. Bill of material was produced.

Item No.	Part Name	Quantity
1	sg90 servo	18
2	Arduino Mega board	1
3	servo clamps	18
4	acrylic sheet (5mm) (3' *2')	1
5	M3 washer	36
6	M4 hexnut	18
7	sg90 gear	18
8	40 mm M3 f-f spacer	18
9	Wero Board	1
10	M3 10 mm screw	36
11	10 KHz resistor	2
12	SMPS	1
13	Connectors	18

Table 5: Bill of Materials

5.2. Motor Specification:

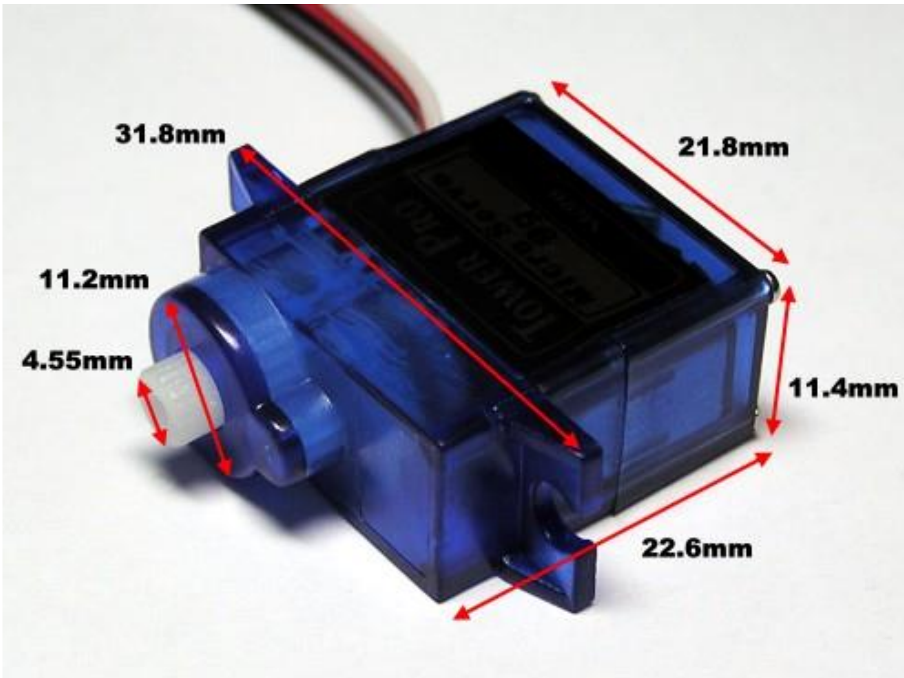


Figure 5.1: sg90 servo dimensions

Basic Information

Modulation:	Analog
Torque:	**4.8V:** 25.0 oz-in (1.80 kg-cm)
Speed:	**4.8V:** 0.10 sec/60°
Weight:	0.32 oz (9.0 g)
Dimensions:	Length: 0.91 in (23.1 mm) Width: 0.48 in (12.2 mm) Height: 1.14 in (29.0 mm)
Motor Type:	3-pole
Gear Type:	Plastic
Rotation/Support:	Bushing

Table 6: sg90 servo basic informations

CHAPTER 6

CONTROL STRUCTURE

6.1. PID Control:

Here Decentralized control architecture is used, where each joint can be controlled by separate servos and micro controller. The interaction of feet with ground is one of the vital aspect to consider in robotics locomotion. And hence a feedback control for the foot force-ground interaction has been introduced. And an Algorithm was written based on the PID scheme.

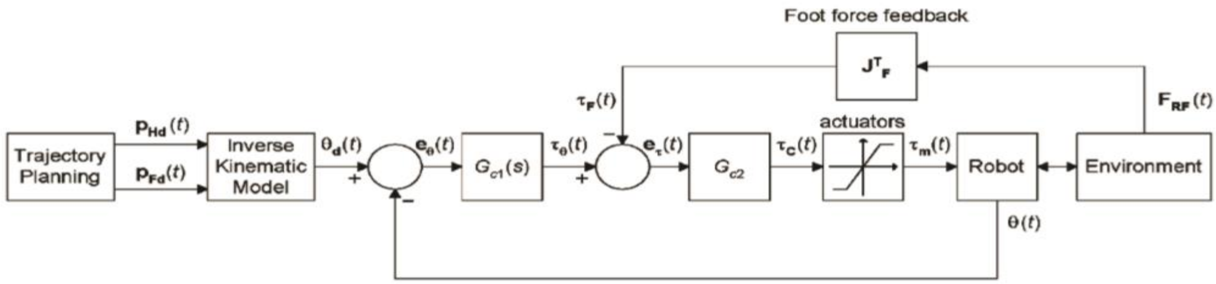


Figure 6.1: Control architecture of Hexapod

Inverse Kinematic s is taken into consideration. As the joint space changes. The leg moves with the COXA reference, not the body reference. Thus use of a translation matrix was needed. Power supply is also vital in the electronics schematics as 18 servos can draw a lot of current. Hence SMPS (switched-mode power supply) has been used.

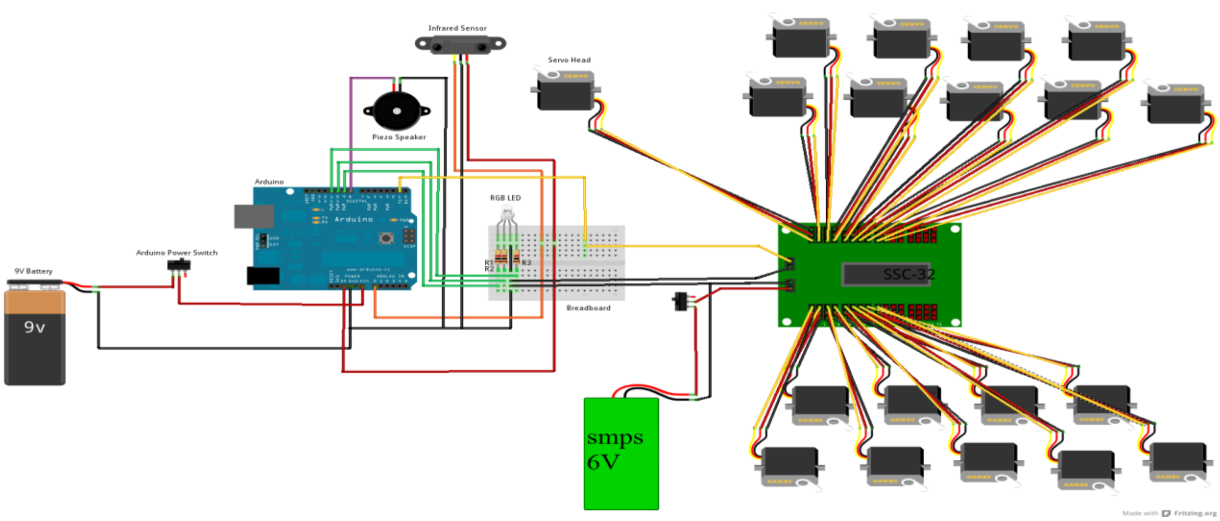


Figure 6.2: Electronic Schematics

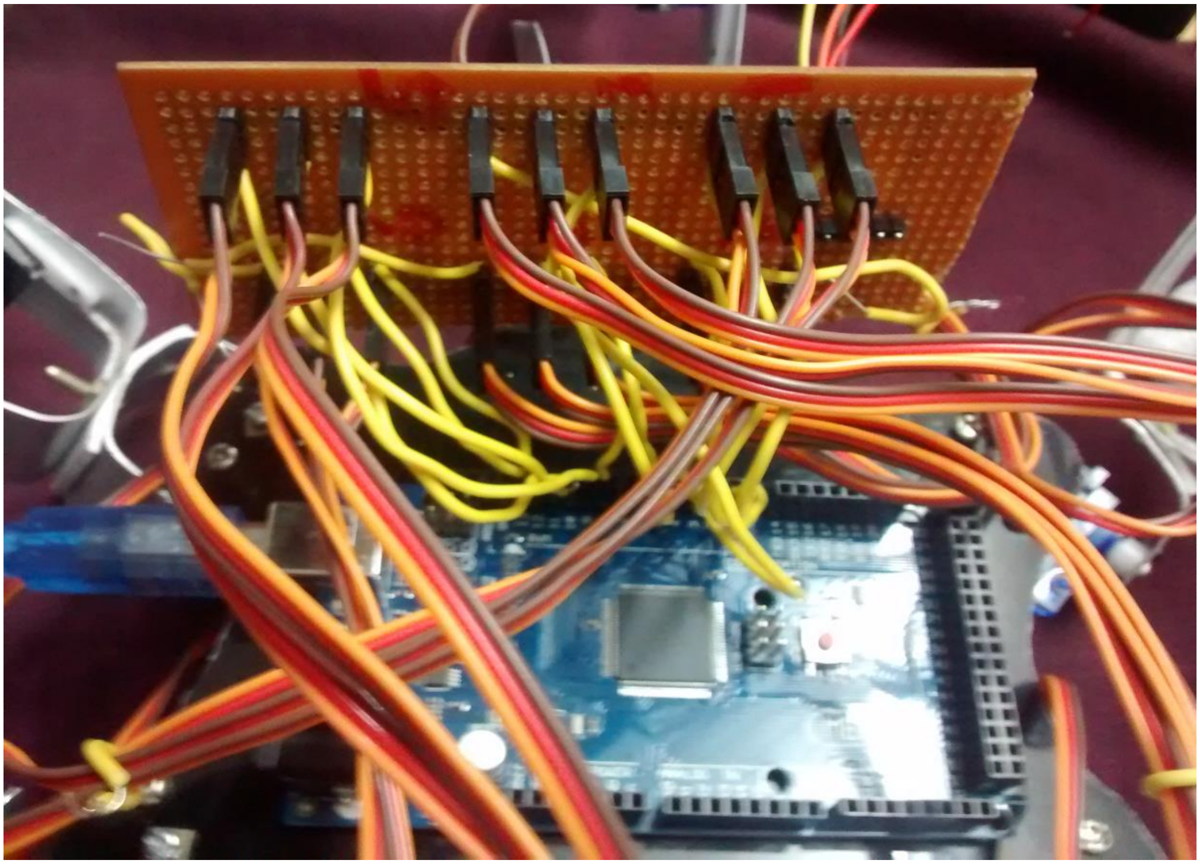


Figure 6.3: Electronic Circuit of the robot

6.2. Gait Selection:

A gait, by definition, is the study of coordinated and sequenced body and leg motion of biological species to fulfill the movement in desired direction. The body orientation study is also important in gait study. This biological concept is also the basis for bio-inspired robot movements. Periodic gaits are basically preferred for gait implementation viz. tripod, wave, ripple etc.

For stability Wave gait was implemented in the discussed Hexapod.

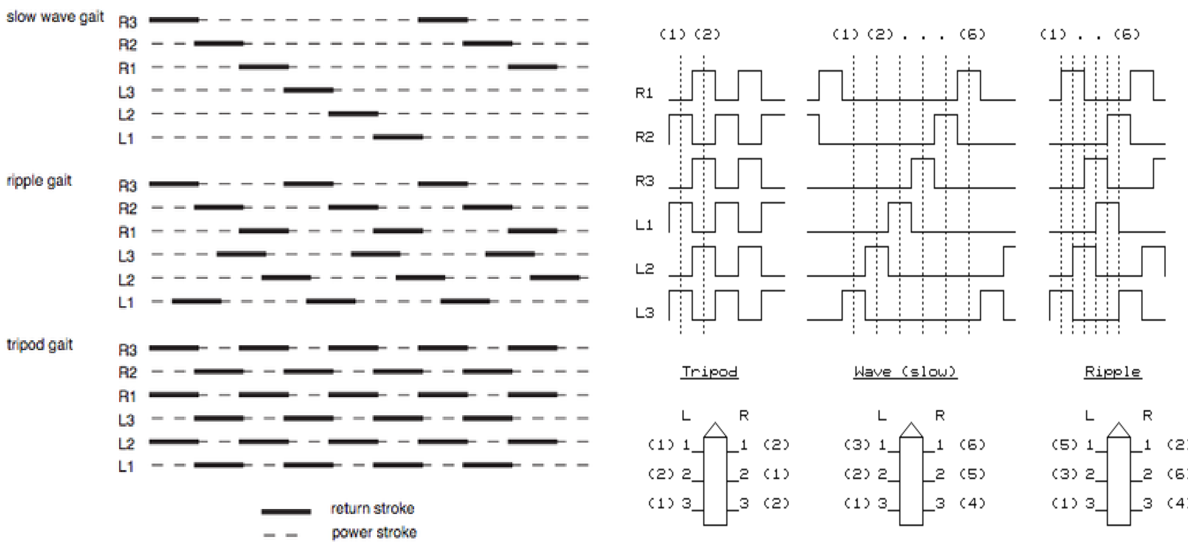


Figure 6.4: Gait implementation

CHAPTER 7

FABRICATION
&
ERROR DISCUSSION

7.1. Fabrication:

After implementation of the gaits and manufacturing of the components the first leg of Hexapod was assembled.

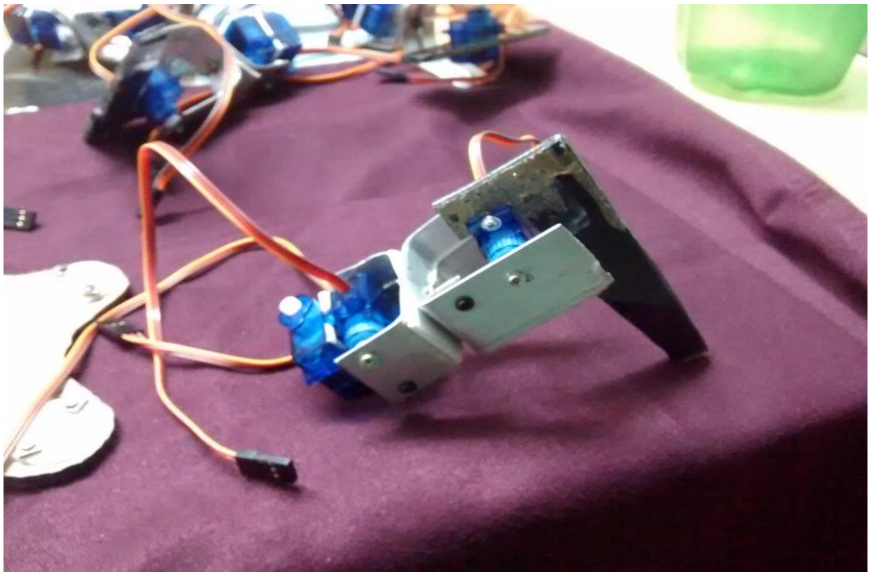


Figure 7.1: Leg Assembly

With the successful movement of the first leg the rest of the legs were assembled and connected to the control board. Different gaits were implemented.

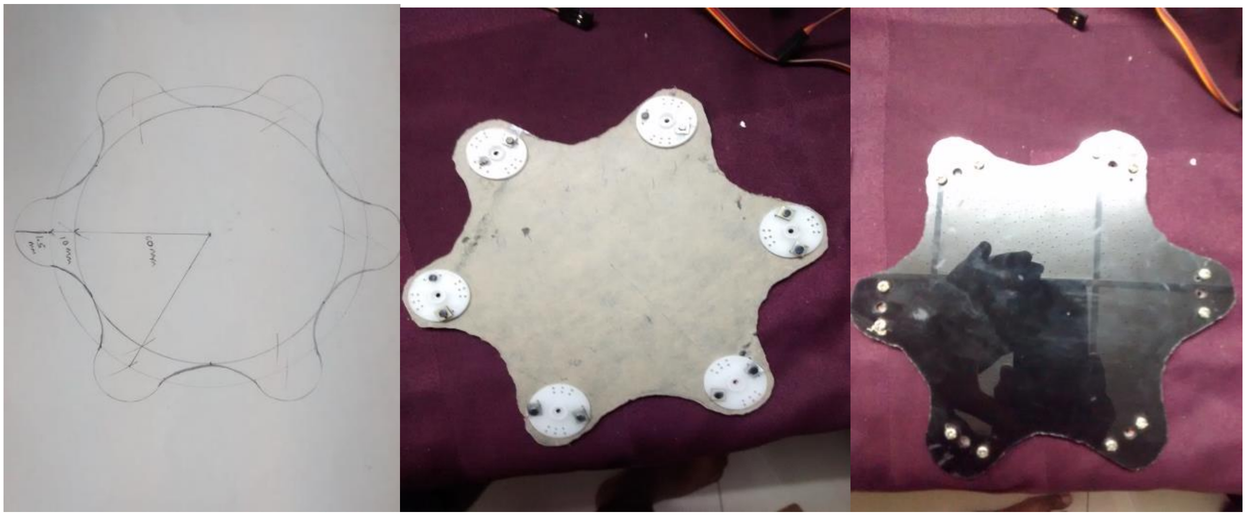


Figure 7.2: Chassis Design

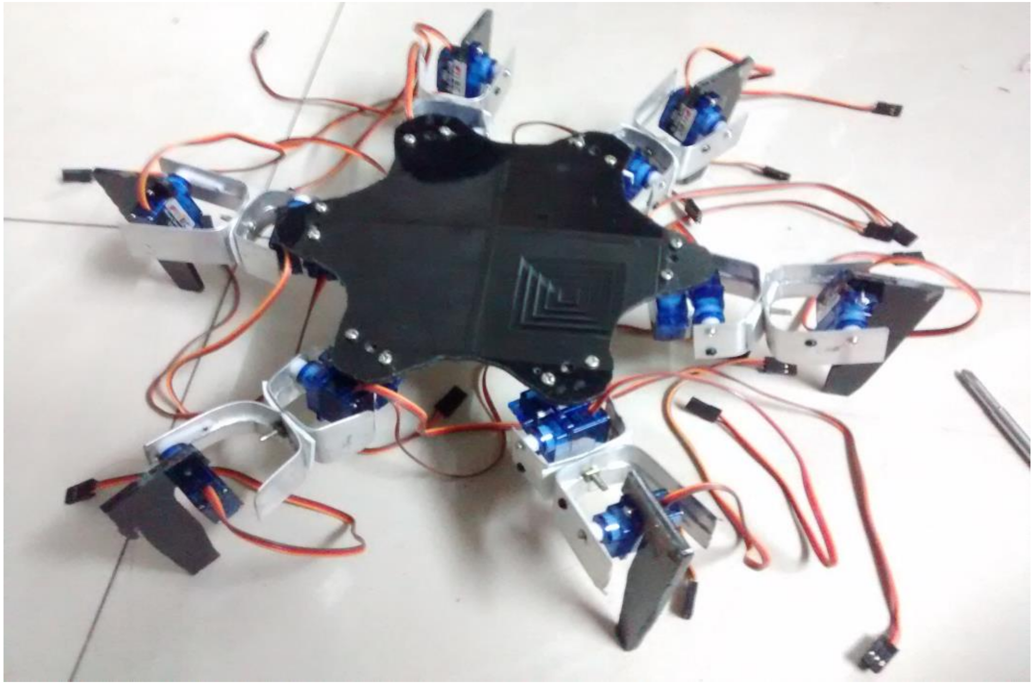


Figure 7.2.a: Robot Assembly without electronics

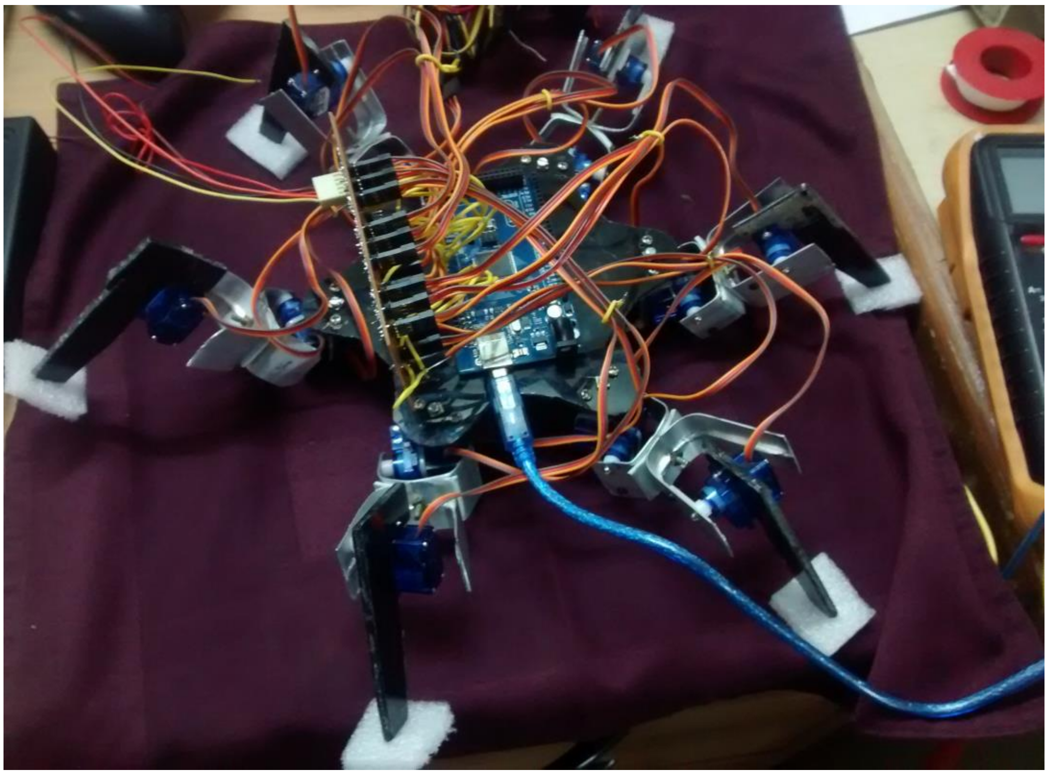


Figure 7.2.b: Robot Assembly with electronics

7.2. Discussion of Error:

Due to the capacity limitations of hexapod, some design changes took place after consideration of body weight. Now evaluating the simulation time of Hexapod for covering distance with the realistic time we get some error. Most of the error in practical experiment was due to connection misfits, structural deficiencies and friction.

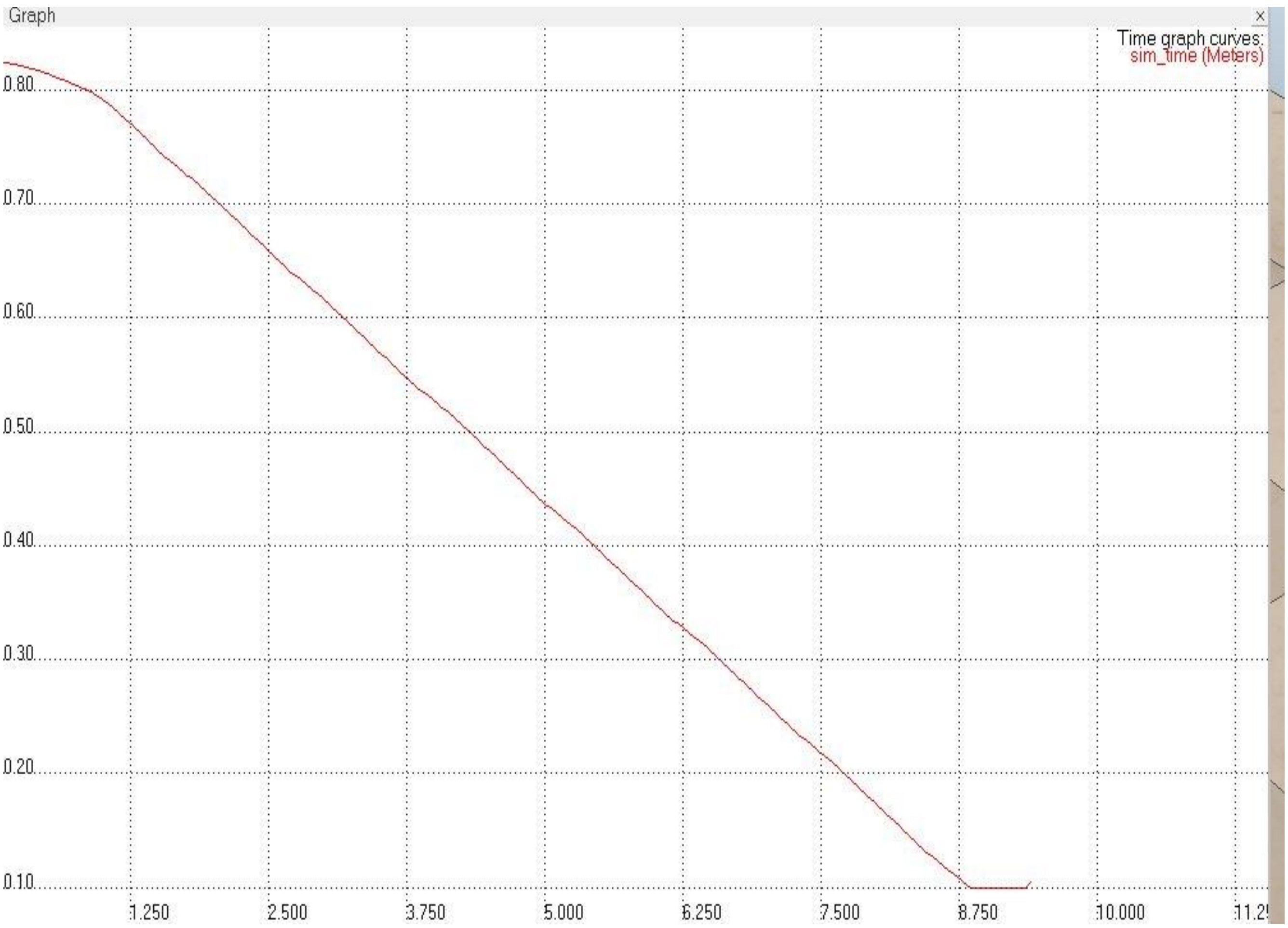


Figure 7.3: Simulation time graph

Standard percentage of error calculation was done using the formula:

$$e = \frac{(T_e - T_s)}{T_s} \times 100 \quad \text{..... Eq.(9)}$$

Sl No.	Distance (in meter)	Simulation time T(s)	Practical time T(e)	Percentage error (e)
1	0.2	2.9	3.2	10.34
2	0.4	5.1	5.5	7.85
3	0.6	7.5	8.1	8.04
4	0.8	10.1	11.06	9.56
5	1.0	12.4	13.62	9.82

Table 7: Error calculation

The percentage error shows that there are some initial glitches while booting up the robot but as the robot moves on the error for the successive distance period keeps decreasing when robot is in full forth, and then again after some time the robot starts to slow down. The error here can be attributed to structural faults, electronics signal interference etc.

CHAPTER 8

CONCLUSION
&
FUTURE WORK

8.2. Conclusion:

This research is motivated by the need for mobile machining systems to remove humans from hazardous and inaccessible environments. The research analyzed the kinematics, dynamics, and stability requirements for mobile machining system based on hexapod walking robots. The major contributions of this dissertation are, model selection based on the House of quality was done. The structural parameters of a HWR were selected, the physical size of the robot was determined. A 3D virtual prototype robot system has been created CATIA V5.The design then exported to V-rep workbench through CATIA to simulate it in real time. V-rep simulation validated the design. Excel spreadsheet simulator was created for better understanding of IK.An accurate and concise analytical inverse kinematic solution for HWR was developed. Solidworks analysis for stress and displacement deformation was carried out. Bill of materials was finalized. A bio-inspired reactive stability control strategy, gait algorithm was developed. Fabrication of the hexapod in line with the developed strategy was completed. Experimental demonstration of the robot and embedment of modern technologies for productive work was done.

8.3. Future Work:

As the project has reached the time limit, the future possibilities to be thought of are further optimization of the design parameters to a prescribed workspace along with GA and Fuzzy Logic implementation in gaits. Developing a full scale industry oriented hexapod in line with this parent design should also be kept in mind. Implementation of sensors for data collection can be implemented for better feedback and complex operation of the Hexapod.

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PUBLICATION:

The paper 'Design and Analysis of a Hexapod' has been forwarded to "International Journal of Artificial Intelligence and Computational Research (IJAICR)" and is under review.

APPENDIX:

```
/* The main algorithm behind the movement of hexapod to implement the wave gate

 */

// Servo.h is the library for controlling servos.
#include <Servo.h>


// each servo motor is positioned at a specific angle
// in order to keep the hexapod in standing condition.
#define normal_leg11 89
#define normal_leg12 0
#define normal_leg13 85
#define normal_leg21 80
#define normal_leg22 0
#define normal_leg23 0
#define normal_leg31 86
#define normal_leg32 0
#define normal_leg33 0
#define normal_leg41 30
#define normal_leg42 0
#define normal_leg43 0
```

```
#define normal_leg51 88
#define normal_leg52 0
#define normal_leg53 0
#define normal_leg61 80
#define normal_leg62 0
#define normal_leg63 0

// delay of 25 miliseconds is given between
// consecutive rotations of different servos.
#define DELAY 100


// Initialize 18 servos, 3 in each legs.
Servo Leg1_1;
Servo Leg1_2;
Servo Leg1_3;
Servo Leg2_1;
Servo Leg2_2;
Servo Leg2_3;
Servo Leg3_1;
Servo Leg3_2;
Servo Leg3_3;
Servo Leg4_1;
Servo Leg4_2;
Servo Leg4_3;
Servo Leg5_1;
Servo Leg5_2;
Servo Leg5_3;
Servo Leg6_1;
Servo Leg6_2;
Servo Leg6_3;

// setup function is called only once at the start.
void setup()
{
//  // begin radio.
//  radio.begin();
//  // assign address of writing pipe.
//  radio.openWritingPipe(pipes[1]);
//  // assign address of reading pipe.
//  radio.openReadingPipe(1, pipes[0]);
//  // start listening from the joystick.
//  radio.startListening();
//
//  // begin temperature sensor.
//  dht.begin();

  // Assign pins to all servo motors.
  Leg1_1.attach(0);
  Leg1_2.attach(1);
  Leg1_3.attach(2);
  Leg2_1.attach(3);
  Leg2_2.attach(4);
//  Leg2_3.attach();
  Leg3_1.attach(5);
  Leg3_2.attach(6);
```

```
//  Leg3_3.attach();
  Leg4_1.attach(7);
  Leg4_2.attach(8);
//  Leg4_3.attach(28);
  Leg5_1.attach(9);
  Leg5_2.attach(10);
  Leg5_3.attach(11);
  Leg6_1.attach(12);
  Leg6_2.attach(13);
//  Leg6_3.attach();
//
  // Since setup() function is called at the
  // begining, so it will move all servos
  // to their normal positions and hexapod will
  // be in standing position.

}


void loop() {
  move2normalAngle();
}
// This function will move all servos to their normal angle.
void move2normalAngle()



{
  // Leg 1
  Leg1_1.write(normal_leg11);
  delay(15);
  Leg1_2.write(normal_leg12);
  delay(15);
  Leg1_3.write(normal_leg13);
  delay(15);
  // Leg 2
  Leg2_1.write(normal_leg21);
  delay(15);
  Leg2_2.write(normal_leg22);
  delay(15);
  Leg2_3.write(normal_leg23);
  delay(15);
  // Leg 3
  Leg3_1.write(normal_leg31);
  delay(15);
  Leg3_2.write(normal_leg32);
  delay(15);
  Leg3_3.write(normal_leg33);
  delay(15);
  // Leg 4
  Leg4_1.write(normal_leg41);
  delay(15);
  Leg4_2.write(normal_leg42);
  delay(15);
  Leg4_3.write(normal_leg43);
  delay(15);
```

```
  // Leg 5
  Leg5_1.write(normal_leg51);
  delay(15);
  Leg5_2.write(normal_leg52);
  delay(15);
  Leg5_3.write(normal_leg53);
  delay(15);
  // Leg 6
  Leg6_1.write(normal_leg61);
  delay(15);
  Leg6_2.write(normal_leg62);
  delay(15);
  Leg6_3.write(normal_leg63);
  delay(15);
}



// This function will move hexapod in forward direction
void moveForward()
{
  // Leg 1
  Leg1_2.write(normal_leg12 - 30);
  delay(DELAY);
  Leg1_3.write(normal_leg13 + 20);
  delay(DELAY);
  Leg1_2.write(normal_leg12 + 10);
  delay(DELAY);
  // Leg 2
  Leg2_2.write(normal_leg22 + 30);
  delay(DELAY);
  Leg2_3.write(normal_leg23 - 20);
  delay(DELAY);
  Leg2_2.write(normal_leg22 - 10);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 30);
  delay(DELAY);
  Leg5_3.write(normal_leg53 - 20);
  delay(DELAY);
  Leg5_2.write(normal_leg52);
  delay(DELAY);
  // Leg 6
  Leg6_2.write(normal_leg62 + 30);
  delay(DELAY);
  Leg6_3.write(normal_leg63 + 20);
  delay(DELAY);
  Leg6_2.write(normal_leg62);
  delay(DELAY);

  // Leg 1
  Leg1_2.write(normal_leg12);
  delay(15);
  Leg1_3.write(normal_leg13);
  delay(15);
  // Leg 2
```

```
  Leg2_2.write(normal_leg22);
  delay(15);
  Leg2_3.write(normal_leg23);
  delay(15);
  // Leg 3
  Leg3_1.write(normal_leg31 + 20);
  delay(15);
  // Leg 4
  Leg4_1.write(normal_leg41 - 20);
  delay(15);
  // Leg 5
  Leg5_2.write(normal_leg52);
  delay(15);
  Leg5_3.write(normal_leg53);
  delay(15);
  // Leg 6
  Leg6_2.write(normal_leg62);
  delay(15);
  Leg6_3.write(normal_leg63);
  delay(DELAY);

  // Leg 4
  Leg4_2.write(normal_leg42 + 30);
  delay(DELAY);
  Leg4_1.write(normal_leg41);
  delay(DELAY);
  Leg4_2.write(normal_leg42);
  delay(DELAY);
  // Leg 3
  Leg3_2.write(normal_leg32 - 30);
  delay(DELAY);
  Leg3_1.write(normal_leg31);
  delay(DELAY);
  Leg3_2.write(normal_leg32);
  delay(DELAY);


  // move all servos to their normal angle
  move2normalAngle();
  delay(DELAY);
}

// This function will move hexapod in backward direction
void moveBackward()
{
  // Leg 6
  Leg6_2.write(normal_leg62 + 30);
  delay(DELAY);
  Leg6_3.write(normal_leg63 - 20);
  delay(DELAY);
  Leg6_2.write(normal_leg62 - 10);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 30);
  delay(DELAY);
  Leg5_3.write(normal_leg53 + 20);
```

```
delay(DELAY);
Leg5_2.write(normal_leg52 + 10);
delay(DELAY);
// Leg 2
Leg2_2.write(normal_leg22 + 30);
delay(DELAY);
Leg2_3.write(normal_leg23 + 20);
delay(DELAY);
Leg2_2.write(normal_leg22);
delay(DELAY);
// Leg 1
Leg1_2.write(normal_leg12 - 30);
delay(DELAY);
Leg1_3.write(normal_leg13 - 20);
delay(DELAY);
Leg1_2.write(normal_leg12);
delay(DELAY);



// Leg 1
Leg1_2.write(normal_leg12);
delay(15);
Leg1_3.write(normal_leg13);
delay(15);
// Leg 2
Leg2_2.write(normal_leg22);
delay(15);
Leg2_3.write(normal_leg23);
delay(15);
// Leg 3
Leg3_1.write(normal_leg31 - 30);
delay(15);
// Leg 4
Leg4_1.write(normal_leg41 + 30);
delay(15);
// Leg 5
Leg5_2.write(normal_leg52);
delay(15);
Leg5_3.write(normal_leg53);
delay(15);
// Leg 6
Leg6_2.write(normal_leg62);
delay(15);
Leg6_3.write(normal_leg63);
delay(DELAY);

// Leg 4
Leg4_2.write(normal_leg42 + 30);
delay(DELAY);
Leg4_1.write(normal_leg41);
delay(DELAY);
Leg4_2.write(normal_leg42);
delay(DELAY);
// Leg 3
Leg3_2.write(normal_leg32 - 30);
```

```
  delay(DELAY);
  Leg3_1.write(normal_leg31);
  delay(DELAY);
  Leg3_2.write(normal_leg32);
  delay(DELAY);


  // move all servos to their normal angle
  move2normalAngle();
  delay(15);
}

// This function will move hexapod towards right
void moveRight()
{
  // Leg 1
  Leg1_2.write(normal_leg12 - 20);
  delay(DELAY);
  Leg1_1.write(normal_leg11 + 20);
  delay(DELAY);
  Leg1_2.write(normal_leg12);
  delay(DELAY);
  // Leg 4
  Leg4_2.write(normal_leg42 + 20);
  delay(DELAY);
  Leg4_3.write(normal_leg43 + 10);
  delay(DELAY);
  Leg4_2.write(normal_leg42);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 20);
  delay(DELAY);
  Leg5_1.write(normal_leg51 - 20);
  delay(DELAY);
  Leg5_2.write(normal_leg52);
  delay(DELAY);
  // Leg 2
  Leg2_2.write(normal_leg22 + 20);
  delay(DELAY);
  Leg2_1.write(normal_leg21 + 20);
  delay(DELAY);
  Leg2_2.write(normal_leg22);
  delay(DELAY);
  // Leg 3
  Leg3_2.write(normal_leg32 - 20);
  delay(DELAY);
  Leg3_3.write(normal_leg33 + 20);
  delay(DELAY);
  Leg3_2.write(normal_leg32 + 5);
  delay(DELAY);
  // Leg 6
  Leg6_2.write(normal_leg62 + 20);
  delay(DELAY);
  Leg6_1.write(normal_leg61 - 20);
  delay(DELAY);
  Leg6_2.write(normal_leg62);
```

```
  delay(DELAY);

  // move all servos to their normal angle
  move2normalAngle();
  delay(DELAY);
}




// This function will move hexapod towards left
void moveLeft()
{
  // Leg 1
  Leg1_2.write(normal_leg12 - 20);
  delay(DELAY);
  Leg1_1.write(normal_leg11 - 20);
  delay(DELAY);
  Leg1_2.write(normal_leg12);
  delay(DELAY);
  // Leg 4
  Leg4_2.write(normal_leg42 + 20);
  delay(DELAY);
  Leg4_3.write(normal_leg43 - 20);
  delay(DELAY);
  Leg4_2.write(normal_leg42 - 5);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 20);
  delay(DELAY);
  Leg5_1.write(normal_leg51 + 20);
  delay(DELAY);
  Leg5_2.write(normal_leg52);
  delay(DELAY);
  // Leg 2
  Leg2_2.write(normal_leg22 + 20);
  delay(DELAY);
  Leg2_1.write(normal_leg21 - 20);
  delay(DELAY);
  Leg2_2.write(normal_leg22);
  delay(DELAY);
  // Leg 3
  Leg3_2.write(normal_leg32 - 20);
  delay(DELAY);
  Leg3_3.write(normal_leg33 - 10);
  delay(DELAY);
  Leg3_2.write(normal_leg32 + 5);
  delay(DELAY);
  // Leg 6
  Leg6_2.write(normal_leg62 + 20);
  delay(DELAY);
  Leg6_1.write(normal_leg61 + 20);
  delay(DELAY);
  Leg6_2.write(normal_leg62);
  delay(DELAY);
```

```
  // move all servos to their normal angle
  move2normalAngle();
  delay(DELAY);
}

// this function will turn hexapod in clockwise direction
void turnClockWise()
{
  // Leg 1
  Leg1_2.write(normal_leg12 - 30);
  delay(DELAY);
  Leg1_1.write(normal_leg11 + 30);
  delay(DELAY);
  Leg1_2.write(normal_leg12);
  delay(DELAY);
  // Leg 4
  Leg4_2.write(normal_leg42 + 30);
  delay(DELAY);
  Leg4_1.write(normal_leg41 + 30);
  delay(DELAY);
  Leg4_2.write(normal_leg42);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 30);
  delay(DELAY);
  Leg5_1.write(normal_leg51 + 30);
  delay(DELAY);
  Leg5_2.write(normal_leg52);
  delay(DELAY);
  // Leg 2
  Leg2_2.write(normal_leg22 + 30);
  delay(DELAY);
  Leg2_1.write(normal_leg21 + 30);
  delay(DELAY);
  Leg2_2.write(normal_leg22);
  delay(DELAY);
  // Leg 3
  Leg3_2.write(normal_leg32 - 30);
  delay(DELAY);
  Leg3_1.write(normal_leg31 + 30);
  delay(DELAY);
  Leg3_2.write(normal_leg32);
  delay(DELAY);
  // Leg 6
  Leg6_2.write(normal_leg62 + 30);
  delay(DELAY);
  Leg6_1.write(normal_leg61 + 30);
  delay(DELAY);
  Leg6_2.write(normal_leg62);
  delay(DELAY);

  // move all servos to their normal angle
  move2normalAngle();
  delay(DELAY);
}
```

```
// This function will turn hexapod in anti-clockwise direction
void turnAntiClockWise()
{
  // Leg 1
  Leg1_2.write(normal_leg12 - 30);
  delay(DELAY);
  Leg1_1.write(normal_leg11 - 30);
  delay(DELAY);
  Leg1_2.write(normal_leg12);
  delay(DELAY);
  // Leg 4
  Leg4_2.write(normal_leg42 + 30);
  delay(DELAY);
  Leg4_1.write(normal_leg41 - 30);
  delay(DELAY);
  Leg4_2.write(normal_leg42);
  delay(DELAY);
  // Leg 5
  Leg5_2.write(normal_leg52 - 30);
  delay(DELAY);
  Leg5_1.write(normal_leg51 - 30);
  delay(DELAY);
  Leg5_2.write(normal_leg52);
  delay(DELAY);
  // Leg 2
  Leg2_2.write(normal_leg22 + 30);
  delay(DELAY);
  Leg2_1.write(normal_leg21 - 30);
  delay(DELAY);
  Leg2_2.write(normal_leg22);
  delay(DELAY);
  // Leg 3
  Leg3_2.write(normal_leg32 - 30);
  delay(DELAY);
  Leg3_1.write(normal_leg31 - 30);
  delay(DELAY);
  Leg3_2.write(normal_leg32);
  delay(DELAY);
  // Leg 6
  Leg6_2.write(normal_leg62 + 30);
  delay(DELAY);
  Leg6_1.write(normal_leg61 - 30);
  delay(DELAY);
  Leg6_2.write(normal_leg62);
  delay(DELAY);

  // move all servos to their normal angle
  move2normalAngle();
  delay(DELAY);
}
```

……